Uncertainties and Interdisciplinary Transfers Through the End-to-End System (UNITES): Capturing Uncertainty in the Common Tactical Environmental Picture

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LONG-TERM GOALS

UNITES is a unique, interdisciplinary team with expertise spanning the environment (physical oceanography and bottom geology), ocean acoustics (propagation, ambient noise, reverberation and signal processing), and tactical sonar systems. The overall goals of the research are to enhance the understanding of the uncertainty in the ocean environment (including the sea bottom), characterize its impact on sonar system performance, and provide the Navy with guidance for understanding sonar system performance uncertainty in the littoral.

OBJECTIVES

Specific objectives of the team effort are to:

1) Develop generic methods for efficiently and simply characterizing, parameterizing, and prioritizing sonar system variabilities and uncertainties arising from regional scales (spatial and temporal) and processes.

2) Construct, calibrate and evaluate uncertainty and variability models, for the sonar systems and its components, to address forward and backward transfer of uncertainties.

3) Transfer uncertainties from the acoustic environment to the sonar and its signal processing, in order to effectively characterize and understand sonar performance and predictions.

APPROACH

Our technical approach is based on utilizing environmental probability density functions (PDF) to provide a description of sonar performance. The PDFs will be determined for appropriate spatial and temporal scales as dictated by the systems under consideration. In particular, these PDFs will be determined for the following: meso- and sub-mesoscale fronts and eddies, tides, internal tides, waves and solitons, interference variability (ambient noise and reverberation) and spatially variable bottoms. In FY02, we have worked with acoustic data from the 1996 Shelfbreak PRIMER exercise and SHAREM data sets from the East China Sea (ECS) and Sea of Japan (SOJ).

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14. ABSTRACT
UNITES is a unique, interdisciplinary team with expertise spanning the environment (physical oceanography and bottom geology), ocean acoustics (propagation, ambient noise, reverberation and signal processing), and tactical sonar systems. The overall goals of the research are to enhance the understanding of the uncertainty in the ocean environment (including the sea bottom), characterize its impact on sonar system performance, and provide the Navy with guidance for understanding sonar system performance uncertainty in the littoral.

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WORK COMPLETED

Abbot is one of two co-leaders on the UNITES Team and has worked closely with the UNITES team members. In particular, the following work has been accomplished over the past year:

* The conceptual basis for the Shelfbreak PRIMER end-to-end system has been specifically defined, including its components, linkages and feedbacks of uncertainty from the environment to the sonar (in conjunction with Harvard University).

* Sonar performance predictions incorporating environmental variability were completed for a simulated passive sonar operating in the East China Sea (ECS) and Sea of Japan (SOJ).

* TL uncertainties in the ECS, including bottom limitations were developed (in conjunction with WHOI).

* PRIMER TL and ambient noise fluctuations are being characterized (in conjunction with NPS and WHOI)

* Uncertainty predictability and simple rules-of-thumb are being developed based on the PRIMER and ASISEX data sets (in conjunction with WHOI).

Furthermore, we have completed analyses of the nature of uncertainty for East China Sea transmission loss measurements. Measurement system uncertainty, environmental uncertainty from internal tides, spatially varying bottom geoacoustics and ordinary range-cycle propagation fluctuations have been characterized and appropriate environmental probability density functions have been developed. The results suggest that the uncertainty in the spatially varying bottom is the dominant mechanism of the acoustic transmission loss in this particular bottom-limited environment.

RESULTS

An example using environmental probability density functions for performance predictions is shown in Figure 1. The predictive probabilities of detection (PPD) curves for a simulated passive sonar operating in the ECS and SOJ summer environments are shown. For each environment, we use two PDFs in the prediction, one consisting of the 1-way TL environmental PDF (given in Figure 2), the other being a System-Based PDF. The latter includes uncertainty in the ambient noise and the source level, in addition to the 1-way TL environmental PDFs. The 1-way TL environmental PDF is convolved with the ambient noise PDF and the source level PDF to result in the system-based PDF used in the simulation.

Figure 1 illustrates that all classes of variability affect the PPD. Their origins could be environmental (TL, ambient noise or reverberation, if active) or, non-environmental (source level/target strength, self noise, recognition-differential, and the like). The variability controls the slope of the PPD versus range, the larger its total σ, the larger the slope. The PPD provides the system operator with a probabilistic representation of the system performance as a function of range and the slope provides the basis for trading the gradual range-dependence of detection probability with mission desiderata. The curves shown in Figure 1 show significant differences of sonar system operation for the two locations, with simulated detection ranges much greater in ECS. The PPD method is useful for incorporating environmental uncertainty into predictions of sonar system performance.

The histograms shown in Figure 2 are based on the difference between the measured TL during the summer at the two locations and a state-of-the-art model with inputs based on environmental idealizations typical of operational forecasting. The histograms are described by their respective means (μ) and standard deviations (σ). Notice the large difference in σs between the two environments (2.0 dB in the ECS vs. 5.9 dB in the SOJ). The bathymetry and geoacoustic properties varied widely with the SOJ test area, thus causing large differences between the TL data and model. The fitted PDFs quantify the difference between predictions of the model and the truth of the data, caused by the stochastic variability of the environment. It illustrates our statistical approach for portrayal of environmental uncertainties that are not captured by a predictive tool.

IMPACT/APPLICATIONS

The primary application is to assist the sonar "prediction community" by providing a probabilistic representation of sonar system performance. The present approach provides a systematic method to incorporate uncertainties due to the environment and to transfer the effects of these uncertainties, in the end-to-end problem through the sonar systems under consideration. The operator can thus use this information to operate the system more effectively and make more informed decisions on search, risk, expenditure of assets (weapons) and assumptions of covertness.

TRANSITIONS

Rules-of-thumb, lessons learned, technical implications for effective environmental sampling strategies for the fleet and other tactical insights will be presented to appropriate fleet personnel. We expect to transition specific uncertainty ideas (rules-of-thumb, sampling strategies) through the ONR Littoral ASW FNC program (Common Tactical Picture and Advanced Estimation of Sensor Performance) and the Advanced Processor Build (APB) program. The latter requires interaction with the Sensor Optimization Working Group (SOWG), chaired by Elenor Holmes. We have also given uncertainty presentations to COMSUBDEVRON-12, New London, CT and COMSUBPAC in Pearl Harbor, HA.

Also, the Multi-Static Active ASW System is currently being transitioned through the Advanced Systems Technology Office (ASTO). Recognition of the uncertainty in acoustic propagation is important for the development of fleet rules-of-thumb and tactical documents. Present uncertainty analyses are being used by ASTO in the development of a tactical memo for system operation in the ECS environment, including rules-of-thumb for effective source and receiver placements.

RELATED PROJECTS

1- The ONR Littoral ASW FNC program (Common Tactical Picture and Advanced Estimation of Sensor Performance) has interest in applying the uncertainty principles to specific FNC sonar systems to be evaluated in the future.

2 – The Multi-Static Active ASW System is currently being transitioned to the Navy through the Advanced Systems Technology Office (ASTO). The predictive probability of detection curves derived from the UNITES Team are being utilized by ASTO in this program.

PUBLICATIONS

OASIS has submitted the following articles to be presented at the Acoustic Variability Conference, to be held at Lerici, Italy, in September 2002:

P. Abbot, and I. Dyer, “Sonar performance predictions based on environmental variability.”

P. Abbot, C. Gedney, I. Dyer, and C.S. Chiu, “Ambient noise and signal uncertainties during the Summer shelfbreak Primer Exercise.”

A. Robinson, P. Abbot, P. Lermusiaux, and L. Dillman, “Transfer of uncertainties through physical-acoustical-sonar end-to-end systems: a conceptual basis.”

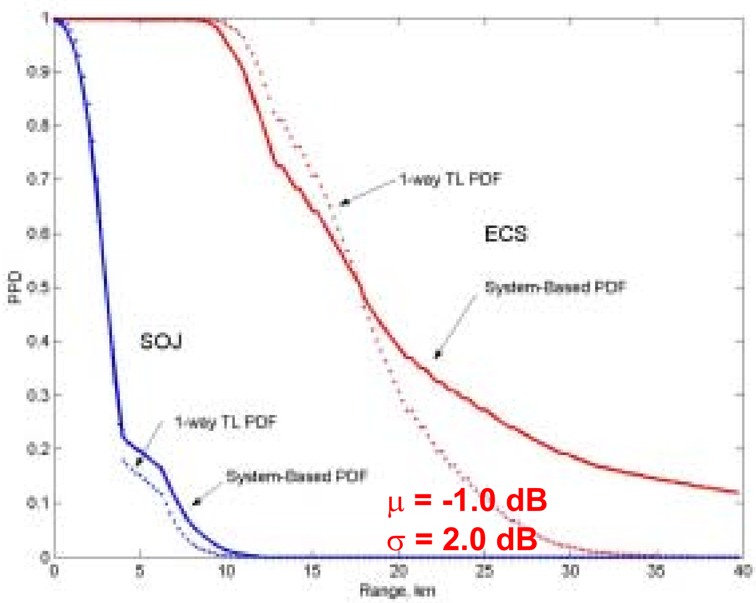

Figure 1: Predictive probabilities of detection (PPD) for simulated passive sonar system operating in the ECS and SOJ, during downward refracting sound speed conditions. The dashed lines are based on a single 1-way TL PDF of uncertainty. The full lines include ambient noise, source level and 1-way TL uncertainties.

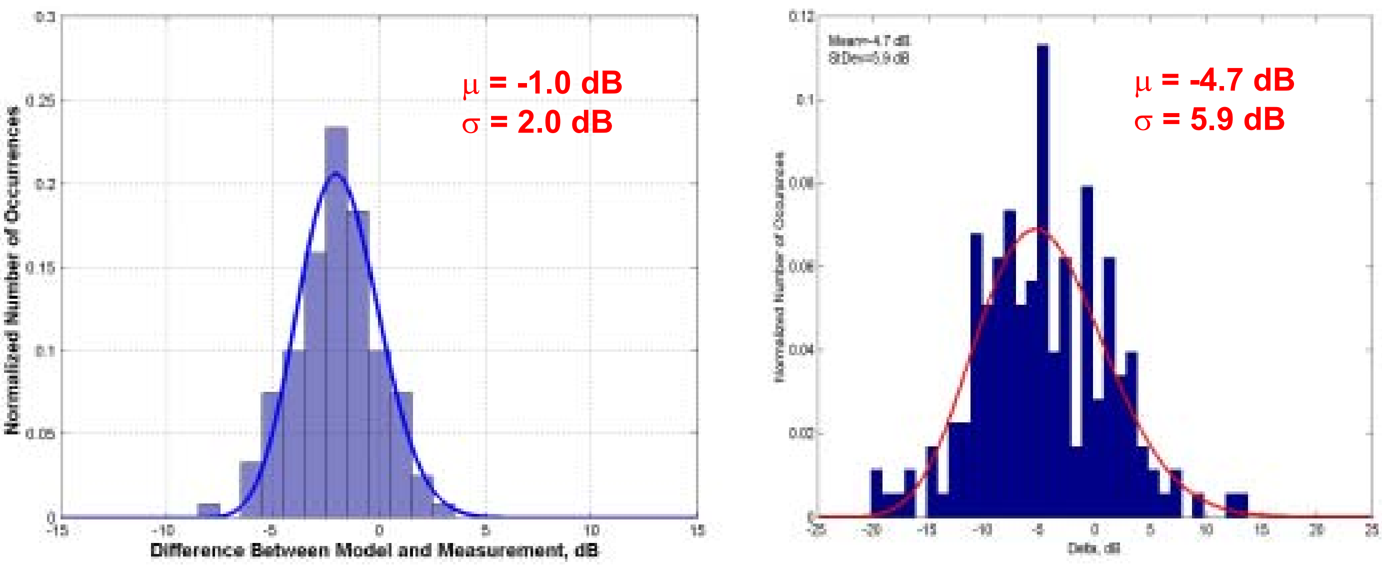

Figure 2: Measured 1-Way TL Environmental PDF, ECS (left) and SOJ (right) with respect to a competent model. The PDF curves are fit to the measured histograms and are considered a useful probabilistic description of the environment's intrinsic variability.